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PHENOLOGY OF EMERGENCE OF THE SPOTTED TENTIFORM LEAFMINER, *PHYLLONORYCTER CRATAEGELLA* (LEPIDOPTERA: GRACILLARIIDAE) AND ITS PARASITOIDS IN NEW YORK

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Abstract.—A phenological emergence study was carried out in Ulster and Orange counties, New York, using the overwintering generation of the spotted tentiform leafminer, *Phyllonorycter crataegella* Clemens and its parasitoids, *Sympiesis marylandensis* Girault, *Sympiesis conica* (Provancher) (Hymenoptera: Eulophidae) and *Apanteles ornigis* Weed (Hymenoptera: Braconidae). *S. marylandensis* was found to emerge concurrently with *P. crataegella,* followed in order by *S. conica* and *A. ornigis. S. conica* also hyperparasitized *A. ornigis* and thus served a dual role in this system.

Introduction

The spotted tentiform leafminer, *Phyllonorycter crataegella* Clemens is a pest of apple trees in the Northeastern United States. It is assumed to be an induced pest, resulting from the suppression of its natural controlling factors due to the use of pesticides intended for other orchard pests. Although the larvae of *P. crataegella* do not directly affect the fruit, the stress they place on the tree can result in reduced yield. High levels of infestation have been implicated in early fruit drop as well. The long term effects of *P. crataegella* upon the host tree are unknown. Recent outbreaks of *P. crataegella* in the Northeast, as recorded by Prokopy et al. (1980) and Weires et al. (1980), have caused concern among growers in the mid-Hudson valley and elsewhere. The appearance of organophosphate-tolerant strains (Weires 1977) has intensified this concern.

Integrated pest management programs, which are gaining acceptance among apple growers, consist of using various pest control techniques while minimizing both adverse environmental effects and farming expenditures. The timing of insecticide applications is a crucial part of this strategy. Since the insecticides affect benefical insects as well as pests, it is important to know at what stages these various insects will be most greatly affected by these treatments and when these vulnerable stages will be present in the orchard to be sprayed. Studies of basic insect biology and phenology serve to improve

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the efficiency of insecticide use by adding to the information which can be incorporated into an integrated pest management program.

In the mid-Hudson valley, 3 species of wasps commonly parasitize *P. crataegella*: *Sympiesis marylandensis* Girault, *Sympiesis conica* (Provancher), and *Apanteles ornigis* Weed. Since these wasps are potential control agents for this moth, their preservation would be a significant factor to be taken into consideration by growers wishing to synchronize or reduce pesticide applications. By knowing the phenological relationships between the various stages of *P. crataegella* and its parasitoids, data gained from procedures used to monitor flights of adult moths could also serve to predict the emergence of the adult parasitoids. The goal of the present study is to determine these phenological relationships.

Biology of the host, Phyllonorycter crataegella.—In the mid-Hudson valley, *P. crataegella* is trivoltine. Pupae overwinter in fallen leaves and adults emerge in the spring. The eggs are laid on the undersides of newly sprouted leaves; upon hatching, the larvae enter the leaves and begin feeding on the spongy mesophyll layer. The first 3 larval instars puncture the plant cells with their sharp mouthparts and feed on the liquids which drain from the cells. These stages are known as sap feeders. Fourth and fifth instar larvae have chewing mouthparts and take bites from the palisade layer of cells, causing a white spotted appearance of the leaf when viewed from above. Silk strands attached to the sides of the mine draw the walls of the mine inward, causing the upper leaf surface to bulge. Pupation occurs within the mine. Prior to eclosion, the pupa pokes its head through the underside of the leaf; the adult emerges, leaving behind the extruding pupal exuvium. The second and third generations follow the same basic pattern. Approximate periods of adult emergence in the mid-Hudson valley, which vary according to the weather conditions, are: April, for the overwintering generation; late June, for the first generation; mid-August, for the second generation.

Emergence of the overwintering generation is fairly well synchronized, but later in the season, individual larvae develop at widely differing rates. As a result, compared to the overwintering generation, the adult flight of the first generation is more spread out in time. By July, all of the life stages are present simultaneoulsy in an orchard. The final flight in August is even more poorly synchronized. Chemical control efforts for this moth have been concentrated in the spring, not only to "nip it in the bud," but also because this is the time when it is assured that those moths present will be in the same or similar stages of development.

Biology of Sympiesis marylandensis *and* Sympiesis conica.—*Sympiesis marylandensis* and *Sympiesis conica* are quite similar in their life histories and habits regarding *P. crataegella* on apple, and details presented here pertain to both species unless otherwise noted. While a *Sympiesis* individual may overwinter as a larva within the mine of the consumed host, the more common situation is overwintering in the pupal stage. After eclosion within the mine, the adult chews a small hole in the leaf and exits.

Behavior of the adults after emergence is not well known. According to Beckham et al. (1950), oviposition by the *Sympiesis* species occurs on hosts in the tissue-feeding stages. Evidence presented by Askew (1979) suggests that in other representatives of the genus *Sympiesis,* adult females may also affect mortality of their *Phyllonorycter* hosts by feeding on the early sap-feeding stages.

A *Sympiesis* larva feeds as an ectoparasite and usually consumes the host, preventing it from reaching the pupal stage. The wasp larva pupates after voiding a small characteristic meconium and extruding a short thread through the anus which serves to anchor it within the mine. In the area of study, at least 3 generations per year occur when *P. crataegella* serves as host.

Biology of Apanteles ornigis.—*Apanteles ornigis* is an endoparasitoid of *P. crataegella* larvae. As in the *Sympiesis* species, the tissue-feeding stages of *P. crataegella* are selected for oviposition by *A. ornigis* females. Although Pottinger and LeRoux (1971) report that overwintering by *A. ornigis* may occur naked in mines of *P. blancardella,* my observations are in agreement with those of Beckham et al. (1950), who found *A. ornigis* overwintering only within a cocoon. *A. ornigis* is the only species of the parasitoid complex of *P. crataegella* which constructs a cocoon; it is an elongate white oval which is attached by a silk thread at each end to the walls of the mine. The actual overwintering stage was undetermined, since it was concealed within the cocoon. Upon eclosion, the adult makes a circular incision so that one end of the cocoon opens as a flap. To emerge from the leaf mine, a small hole is chewed through the leaf epidermis.

Materials and Methods

During the apple growing season of 1979, several orchards in Ulster County and Orange County, New York, were surveyed in order to locate infestations of *Phyllonorycter crataegella* and to determine which parasitoids were attacking it. The presence of *P. crataegella* was apparent to the naked eye, the apple leaves showing the typical spotted mines where moth larvae were present. To locate populations of parasitoids, mined leaves were dissected. Pupating parasitoids were placed individually in #3 gelatin capsules, so that emerging adults could be identified.

The following sites in Ulster County were selected as locations for the collection of data: Turkey Hill plot, MacIntosh Farm plot and Home plot, VanDuser Orchards, Wallkill; DiStefano Orchards, Modena; E. Wright Orchards, New Paltz; Haetzler Orchards, Wallkill; and Gerken Orchards, Wallkill. Data were also collected from Finelli Orchards in Savilton, Orange

County. All collections were made from orchards in commercial production, receiving regular spray programs.

Only the Finelli Orchards site showed a sizeable population of *A. ornigis,* and a separate set of rearings was carried out using material from this site; description of this rearing experiment will appear near the end of this section.

Since the host moths and all of the parasitoids overwinter within the fallen apple leaves, collections of live insect material could be made by gathering leaves from the ground during the winter. Leaves from the various test sites were collected during one of two field trips, the first in December 1979 and the second in March 1980. Infested leaves were placed into rearing chambers made from empty one gallon translucent plastic jugs. The top of each jug was removed and replaced with a clear plastic specimen jar. Although the juncture of the jug and the jar was not airtight, the space between the two was too narrow to allow any of the insects under study to escape.

In an attempt to keep conditions within the rearing chambers as similar as possible to conditions in the orchards of origin, chambers were held out of doors on the porch of the Gambino residence, Bronx, New York. There they received afternoon sun and were sheltered from precipitation. A wooden enclosure, open on top, protected them from wind disturbance, but allowed light to reach the plastic jars at the tops of the chambers.

Insects emerging from the leaves in a chamber were attracted to the light at the top and gathered in the clear jar. All adults were collected on a daily basis, using an aspirator. After recording the date and chamber number, the insects were identified and placed individually in #3 gelatin capsules for future reference.

For the Finelli orchard, in addition to the procedure described, a more intensive rearing experiment was conducted. Infested leaves were gathered in March 1980, and leaves bearing *P. crataegella* mines were dissected until 100 healthy occupants were found. Health was judged from the appearance of the pupa; if it was not crushed or dented, and showed no signs of fungus growth, then it was selected. In the case of an *A. ornigis* cocoon, it was impossible to determine the actual condition of the inhabitant, so the outward appearance of the cocoon was used as a guide.

Insects were placed individually into #3 gelatin capsules and held indoors. The capsules were kept near a window, and thus were exposed to a natural photoperiod. Room temperature was approximately 70°F. As insects emerged, a record was made of the date, species of insect, and whether emergence was from an *Apanteles* cocoon or a naked pupa.

Determination of *P. crataegella* was made by Dr. Don Davis, Smithsonian Institution, Washington, D.C. Determinations of the 2 *Sympiesis* species were made by Dr. E. E. Grissell, U.S. National Museum, Washington, D.C., and the determination of *A. ornigis* was made by Dr. Paul Marsh, also of the U.S. National Museum.

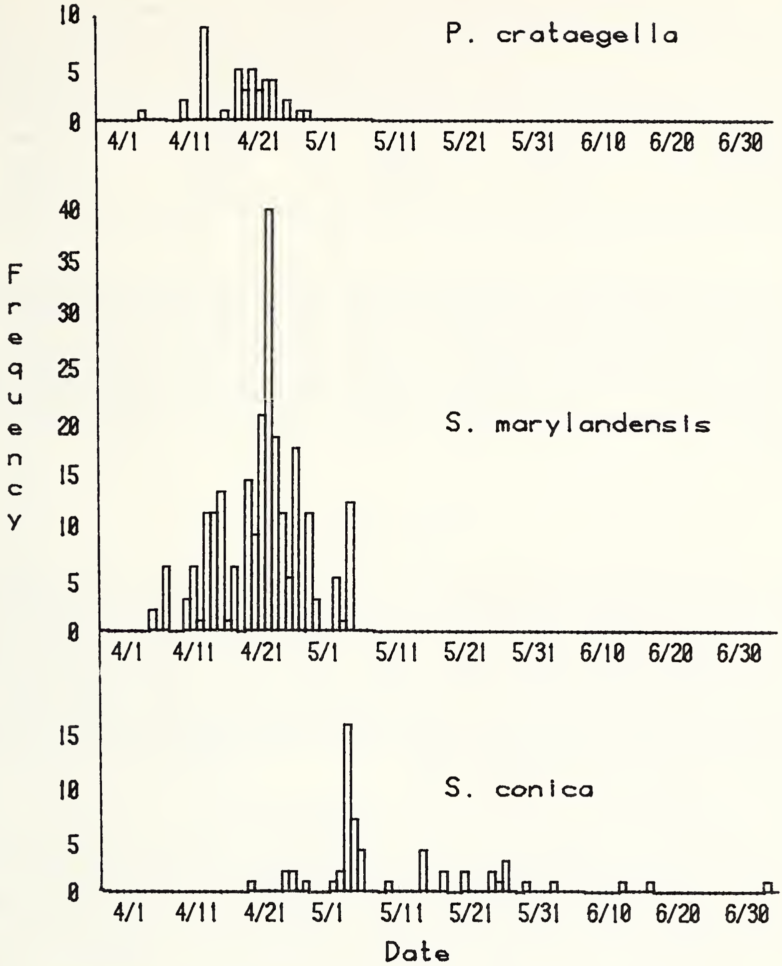

Fig. 1. Rearing chamber emergence frequencies of overwintering insects.

Results

The data gathered from the rearing chambers, pertaining to the emergence of *P. crataegella, S. marylandensis* and *S. conica* are combined and presented in Fig. 1, while Table 1 lists significant emergence dates for these 3 species. Due to the low number of individuals recovered, *Apanteles ornigis* (3) and other unidentified hymenopterous species (6) were not included in the presentation of rearing chamber data.

Data from the separate rearing of insects from the Finelli orchard are presented in Table 2. Of the 100 pupae or cocoons isolated in capsules, 82

Table 1. Rearing chamber emergence dates of *P. crataegella, S. marylandensis* and *S. conica.*

	Dates of emergence			
	N	First	Last	Median
P. crataegella	41	3 April	27 April	18 April
S. marylandensis	230	3 April	2 May	20 April
S. conica	56	18 April	2 July	3 May

yielded adult insects; the 18 mortalities did not receive further consideration. In addition to the 4 species which are the main concern of this study, an unidentified fifth species, recovered only as an *A. ornigis* hyperparasite, was also present in the Finelli orchard. Data concerning the occurrence of this unidentified species are included in Table 2, but are not subject to further analysis.

Discussion

The rearing chamber data (Fig. 1) show that *P. crataegella* adults appeared in April, with most (34/41 or 83%) emerging between 12 April and 22 April inclusive. With a larger sample, it is likely that recordings would have been made in late March and early May. During this time, the first leaves of the apple trees were also appearing, so that the behavior of the moths was well synchronized with phenological events of the host plant; young leaves were available to serve as oviposition sites.

Like *P. crataegella, S. marylandensis* emerged primarily during April. This species is recorded by Beckham et al. (1950) as an ectoparasitoid of *P. crataegella* fourth and fifth instars. At the very least, there would be 2 weeks between *S. marylandensis* emergence and appearance in the field of these suitable stages of *P. crataegella.* A more typical time interval would be 4 weeks. As has been previously noted, post-emergence behavior of these wasps is poorly known. Studies currently underway may shed some light on what *S. marylandensis* does during the weeks prior to oviposition. Despite its seemingly early emergence, *S. marylandensis* has become the dominant *P. crataegella* parasitoid in the area of study.

Sympiesis conica presented an emergence pattern quite different from that of *S. marylandensis.* Initial *S. conica* appearance on 18 April was more than 2 weeks after the first *S. marylandensis* emergence, and occurred while the latter was reaching peak emergence. Overwintering *S. conica* continued to emerge until 2 July, showing a rather diffuse pattern of emergence. When the emergence data from *P. crataegella* and the 2 *Sympiesis* species are analyzed using a median contingency table test, the hypothesis of identical median emergence dates is rejected at the 0.01 level. When just *P. crataegella* and *S. marylandensis* are considered using the median test, no significant

Table 2. Emergence dates for Finelli orchard material.*

Date	*P.c.*	*S.m.*	*S.c.*	*A.o.*	Other
4/19		2			
4/20		2			
4/21		1			
4/22	1	15			
4/23		8			
4/24		4			
4/25		6	1		
4/26		4	1		
4/27			2**		
4/28		2	1**		1**
4/29		2	3**		1**
4/30			3**		
5/1				1	
5/2				2	1**
5/3			1	2	
5/4				2	
5/5				2	
5/6				3	
5/7				3	1**
5/8				1	
5/9				1	
5/10					
5/11				1	

* Key: *P.c.—P. crataegella*; *S.m.—S. marylandensis*; *S.c.—S. conica*; *A.o.—A. ornigis*.
** Indicates hyperparasitism.

difference in the median emergence date is found ($P < 0.05$), confirming what Fig. 1 and Table 1 suggest: *P. crataegella* and *S. marylandensis* emerge concurrently, while *S. conica* appears later in the spring. Indeed, since by 2 July development of the second generation of *P. crataegella* larvae was underway, adults of the overwintering generation of *S. conica* overlapped with 2 generations of hosts in the field.

Several additional observations support the contention that *S. conica* emerges later than *S. marylandensis*. When later generations of parasitoids are considered during the growing season, *S. conica* adults are seen to emerge consistently later than those of *S. marylandensis*. Gathering accurate data on these later generations is difficult, due to the fact that individuals of a population are not well synchronized as they pass through developmental stages and generations may overlap. In the case of parasitoids found to be overwintering as larvae, the majority of those successfully reared turn out to be *S. conica*. Occasionally a parasitized mine contains a parasitoid pupa and the remains of a *P. crataegella* pupa. These rearings also yield *S. conica*. In the case of hyperparasitized *A. ornigis*, *S. marylandensis* was not found to function as an *A. ornigis* hyperparasitoid on apple, while *S. conica* was commonly recovered from *A. ornigis* cocoons (Table 2). This would suggest that oviposition by *S. conica* occurred after *A. ornigis* had reached its cocoon spinning stage. Thus it appears that the developmental schedule of *S. conica* lags behind that of *S. marylandensis* throughout the year.

The limited data on *A. ornigis* suggest that it is the final species of this complex to appear in the spring. However, this generalization certainly would not apply to all individuals. *S. conica,* with its extreme variability in emergence dates, actually overlapped with all 3 other species, and was the species with the final recorded emergence from the rearing chambers. Data from Table 2 indicate that *A. ornigis* emerges after *S. conica.* These data are consistent with those of Johnson et al. (1979), who found that in Ontario, Canada, the difference in median emergence dates between *P. blancardella* (a species similar to *P. crataegella*) and *A. ornigis* was approximately 3 weeks.

A. ornigis is heavily hyperparasitized (17 of 35, or 48%), hyperparasitism being determined when an *A. ornigis* cocoon yielded an adult of a species other than *A. ornigis.* It was necessary to dissect mines in order to assess the impact of hyperparasitism, and this time-consuming procedure was followed only for the additional series of rearings carried out using material from the Finelli orchard. (To the author's knowledge, this is the first record of *A. ornigis* serving as a host for *S. conica.*). Data collected from the rearing chambers cannot give an accurate picture of either the presence or degree of hyperparasitization of *A. ornigis,* especially since the predominant *A. ornigis* hyperparasitoid, *S. conica,* also attacks the primary host, *P. crataegella.*

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